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THE USA FAST NEUTRON BEAM DOSIMETRY PHYSICS GROUP EXPERIENCE WITH IONIZATION CHAMBERS**

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In the USA fast neutron radiation therapy trials began in October, 1972, at the M.D. Anderson Hospital and Tumor Institute and the Texas A&M Variable Energy Cyclotron. Since then, five more facilities have treated human subjects with curative intent in this country. These groups and a resume of some aspects of their dosimetric practices are presented here. A group at the Sloan-Kettering Institute is also included in this overview because their direct contributions and interest in this clinical work are very important.

This report has been written as a reference for those who are planning the use of fast neutron beams in medicine and/or radiobiology. The data is presented mostly in tabular form to emphasize the similarities and dissimilarities of practices among American institutions.

1. Therapy Centers Contributing Information

The groups that have been involved in clinical studies of fast neutron beam radiation therapy and SKI are given below in two listings. The first one includes the name of the institution, the name of appropriate spokespersons for dosimetry questions, and mailing addresses. The second listing (Table I) gives their neutron beam source, nominal total (gamma plus neutron) dose rate in rad/min at D_{max}, at the stated source-to-skin distance (SSD) in cm, for a 10 x 10 cm^2 beam, and the date patient irradiations began.

a. Institutions and Spokespersons

Under the name of some institutions two people are listed. If one is marked with an asterisk(*), he is the one who provided information to the author.

M.D. Anderson Hospital and Tumor Institute (MDAH)
Houston, Texas 77030
Peter Almond and James Smathers*[1]

University of Chicago, Department of Radiology (U of C)
P.O. Box 442, Chicago, Illinois 60637
Franca Kuchnir

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Cancer Therapy Facility (FNAL)
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510
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Great Lakes Neutron Therapy Association (GLANTA)
Cleveland Clinic,
9500 Euclid Avenue, Cleveland, Ohio 44106
John Horton and William K. Roberts*[2]

Mid Atlantic Neutron Therapy Association (MANTA)
Naval Research Laboratory,
Washington, D.C. 20375
Phillip Shapiro and Frank H. Attix*[3]

Sloan-Kettering Institute (SKI)
Biophysics Laboratory
1275 York Avenue, New York, New York 10021
Joseph McDonald

University of Washington (U of W)
Medical Radiation Physics, RC-08
Seattle, Washington 98195
Jüri Eenmaa

Notes:

1. James Smathers' address:
   Texas A&M Variable Energy Cyclotron
   Bioengineering Program, College Station, Texas 77843

2. William K. Roberts' address:
   NASA Lewis Research Center
   21000 Brookpark Road, Cleveland, Ohio 44135

3. H. Attix's address:
   Department of Radiology, University of Wisconsin
   Madison, Wisconsin 53706

b. Beams, SSDs, and Dates of First Patient Treatment

TABLE I

Institution	Neutron Beam	Typical Dose Rate rad/min	SSD cm	First Patient Treatment on
MDAH	d(50MeV)Be	60 w/filter	140	Oct., 1972
U of C	d(8MeV)D_2	20	100	May 24, 1979
FNAL	p(66MeV) Be(49MeV)	40-50	153*	Sept. 8, 1976
GLANTA	d(25MeV)Be	20-40	125	Nov., 1977
MANTA	d(35MeV)Be	55-60	125	Sept., 1973**
SKI	d(8MeV)D_2 d(8MeV)Be	1 11	100	Not applicable
U of W	d(21.5MeV) Be(16MeV)	30	150	Sept. 10, 1973

* This will soon be changed to 190 cm.

** Irradiation of patients ended on June 30, 1979, for lack of funds.

2. Ionization Chambers and Gases

All the USA institutions involved in patient treatment with fast neutron beams have made use of commercially available ionization chambers for measurements of dose in phantom and kerma in air as well as daily verification of the calibration of the neutron beam monitors. The commercial sources for these chambers are given. Their most commonly used models are listed and very briefly described below. These chambers are commonly filled with air for routine measurements and TE gas for absolute dosimetry. An exception is FNAL that uses air for all purposes.

The number of each type of chamber owned by the institutions and the operational polarizing voltages used for routine dosimetry are also listed.

a. Manufacturers

Exradin, Inc.

This company began business in Joliet, Illinois. It changed ownership in February, 1979. Its new address is: 245 W. Roosevelt Road, Bldg. 1-5, West Chicago, Illinois 60185, USA.

b. Far West Technology, Inc. (FWT)

This company received the molds and know-how for chamber fabrication from EG&G. EG&G is no longer manufacturing chambers for commercial purposes. The FWT address is: 330 D. South Kellogg, Goleta, California 93017, USA.

b. Listing of Some Ionization Chambers

These chambers are those in use by the clinical groups listed in section 1. Some of their characteristics are given in Table II. Both manufacturers produce a number of chamber types not listed here.

TABLE II

Model	Shape	Volume cc	Wall Mat'l.	Wall Thickness
EXRADIN				
T-2	Th	0.5	A-150	1mm
Mg-2	Th	0.5	Mg	1mm
T-1	Th	0.05	A-150	1mm
FAR WEST TECHNOLOGY				
IC-17	Sp	1.	A-150	$.57 g/cm^2$
IC-17G	Sp	2.	C	$.54 g/cm^2$
IC-17M	Sp	2.	Mg	$.54 g/cm^2$
IC-18	Th	0.1	A-150	$.18 g/cm^2$
IC-18G	Th	0.2	C	$.30 g/cm^2$
EIC	Parallel Plates	Variable	A-150	Graded Absorb.

Th = Thimble, Sp = Spherical

c. Chamber Ownership by Institution

The number of chambers of each type and the nominal operating ionization collection potential for routine dosimetry is given for each institution in Table III. Some of these institutions use both positive and negative potentials in special dosimetric situations.

TABLE III

Model / Institution	T 2	Mg 2	T 1	IC 17	IC 17G	IC 17M	IC 18	IC 18G	EIC
MDAH				1 -500		1 -500	2 -500		1 -250*
U of C	3 ±300	2 ±300		1 ±500	1 +500		1 ±250		
FNAL	3 +600			4 +600	1 +600	1 +600	4 +300	1 +300	1** +600
GLANTA				2 +412		1 +412	2 +112		2 +200
MANTA				6 -250	1 -500	1 -500	4 -250		1 -250
SKI	2 +250	1 +250	1 +250	2 +250	1 +250	1 +250	1 +250		1 +250
U of W				3 -500	1 -500		3 -500		1** -300

* Operated with a 3.2mm spacing.
** Operated with a 2.2mm spacing.

3. Types of Electrometers

A variety of electrometers are used. In most cases, the low impedance analogue output is read with a 0.1% or a 0.01% accuracy digital voltmeter or an appropriate analogue to digital converter (ADC). At times, user supplied external capacitors are employed. In such cases the dielectric material is mentioned. This information is in Table IV, where K# is Keithley Model Number.

TABLE IV

Institution	K#616*	Others	Dielectric Material
MDAH		K#602, K#610C, Brookhaven Instrument Corp., #1000	
U of C		Cary #401	Air or polystyrene
FNAL	2	9 home built using K#301 preamp	Air or polystyrene
GLANTA	3		
MANTA	1	Cary #401	Polystyrene
SKI	1	K#602, K#640	Polystyrene
U of W	1	Princeton Applied Research Model #135	Air

4. Ionization Chamber Calibrations and System Verifications

To perform absolute dosimetry, the calibration of the ionization chamber and the integrity of the electronics system must be verified. Some institutions check only the system as a whole, namely, ionization chamber plus charge digitizer. Other institutions check the ionization chamber and the charge digitizer both separately and together as a system. Both procedures are acceptable.

In particular, the ionization chamber may be calibrated absolutely in a photon beam of known exposure rate or the constancy of its calibration may be checked with the aid of a check source and reproducible geometry.

Similarly, the electronics system may be directly calibrated by electronic means or it may be checked by substitution with a totally different electronics system while using for both the same constant current source such as an ionization chamber and a check source.

Verification of accuracy of thermometers and barometers are made infrequently except at Fermilab where the digital barometer is checked against an aneroid barometer every treatment day.

Table V gives a summary of these procedures.

TABLE V

Inst.	Ionization Chamber Calibration	Electronics System
MDAH	Absolute: approx. every 6 months in ^{60}Co beam (once at NBS, ^{60}Co).	Air capacitor plus voltage step.
U of C	Absolute: approx. 2-6 times per year in ^{60}Co beam. Check: intercomparison with ^{226}Ra check source each day patients are treated.	Checked as a system with ion chamber.
FNAL	Absolute: yearly at NBS, ^{60}Co beam. Check: intercomparison with ^{137}Cs check each day patients are treated.	Checked weekly by substitution of computer operated system by Keithley #616 and manual timer.
GLANTA	Absolute: once in ^{60}Co at Regional Calibration Laboratory (Victoreen). Check: intercomparison with ^{137}Cs check source monthly.	Checked with current source weekly. Current source calibrated 4 times per year.
MANTA	Same as FNAL, except every 2 years for NBS calibration.	Checked as a system with ion chamber.
SKI	Absolutely: (with formal certificate) every 2 years, ^{60}Co at Regional Calibration Laboratory (Memorial). Check: every 2 weeks (or as needed) using the above facilities.	Checked as a system with ion chamber, and independently with current source.
U of W	Absolute: in therapeutic ^{60}Co beam at own's hospital, approx. every 2 months.	Checked as a system with ion chamber, and independently with current source.

5. Reporting Dose

The practice among the American institutions has been to do neutron beam dosimetry using A-150 wall ionization chambers in a tissue equivalent solution. Then, the charge collected is interpreted as neutron dose.

Work has been in progress for some time at various institutions to separate the total dose into photon and neutron components. In this endeavor, not only ionization chambers with walls made of A-150, C, and Mg have been used but also energy compensated Geiger counters and microdosimetric techniques using A-150 and graphite wall proportional counters. However, the information so gained has not yet found its way into clinical usage.

The formulae and constants used for dosimetry by the American facilities are given in great detail in the "Protocol for Neutron Beam Dosimetry" prepared by Task Group #18, Fast Neutron Beam Dosimetry Physics of the American Association of Physicists in Medicine.* The current draft is #4 (June 29, 1979).

There is a fifth draft of the American protocol now in preparation. When it will be finished, a copy will be mailed to ECNU.

6. Dosimetry Intercomparisons

From the earliest days of fast neutron radiation therapy, the institutions first intercompared the calibration of their ionization chambers in ^{60}Co beams. Then, the calibration of their electronic instrumentation was checked. Finally, determinations were carried out of the kerma in air and dose at various depths in phantom for the neutron beam of the host institutions. The phantom was filled with tissue equivalent solution having a density of $1.07 g/cm^3$.

Typical results of ^{60}Co calibration intercomparisons and in beam neutron measurements are given below. For the neutron dosimetry the conversion factors adopted by the host institutions were used. The results presented in Table VI cover the last two years only.

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TABLE VI

Site & Date	Participants	Intercomparisons[1]	
		Photons[2]	Neutrons[3]
FNAL 8/5/77	MANTA, U of W	0.2%	0.5%
GLANTA 11/15/77	FNAL	1.6%	0.4%
FNAL 11/30/77	GLANTA, MANTA	0.2%	———
FNAL 1/30/78	MDAH	0.2%	0.1%
GLANTA 2/7/78	MDAH	0.6%	1.8%
U of W 1/15/78	SKI	0.5%	1.2%
FNAL 6/17/78	SKI	0.09%	1%
MDAH 7/19/78	SKI	———	0.5%
MANTA 12/16/78	SKI	0.4%	2.1%
U of C 12/7/78	MDAH, U of W	1.4%	0.7%

Notes
(1) Maximum deviation among the various calibrations. Ionometric results only are quoted here.
(2) ^{60}Co or ^{137}Cs calibrated in terms of ^{60}Co for IC-17 chambers.
(3) Neutron beam at host site.

7. Dosimetry by Calorimetry versus Ionometry

A portable calorimeter was developed at SKI under an NCI grant. Now, it is being taken to various neutron therapy facilities for dosimetry intercomparisons. At each facility, the dose delivered by the host institution was measured by the SKI team by ionometric and calorimetric methods. The results of the intercomparisons completed so far are given in Table VII for in phantom measurements.

TABLE VII

Site	Date	Dose Radio[1]
U of W	1/15/78	0.996
NRL	12/6/78	1.021[2]
MDAH	7/19/78	0.997
FNAL	6/17/78	1.013

(1) $\text{Dose Ratio} = \dfrac{\text{Host Ionometric Dose Determination}}{\text{SKI Calorimetric Dose Determination}}$

(2) This was the first intercomparison. The calorimeter was not operating very stably at that time.

8. Beam Monitoring for Therapy

All USA institutions involved in fast neutron radiation therapy use transmission ionization chambers and charged particle beam current integrators to monitor and stop the patient irradiation. The transmission chambers have parallel plates. Some information on plate materials, chamber construction and digitizers for the charge integrators is given in Table VIII. Some of these chambers are double, namely, they have two sets of independent parallel plates and outputs for digitizers.

TABLE VIII

Institution	Transmission Chamber	Digitizer
MDAH	Aluminum plates G-10 insulators Sealed	Brookhaven Instruments Corp. Current to frequency converter.
U of C	Aluminum plates Alumina insulators Open to atmosphere	Home built with ADC
FNAL	Aluminum plates Alumina insulators Open to atmosphere Continuous correction for pressure and temperature	Home built integrator that operates synchronously with linac pulses plus ADC.
GLANTA	Polystyrene plates with Aquadag electrodes Polystyrene insulators Open to atmosphere	Home built digitizer based on VFC.
MANTA	Polystyrene plates, evaporated with aluminum Self-insulating Open to atmosphere	Home built digitizer using VFC.
U of W	Polystyrene plates and aluminum screen Lucite insulators Open to atmosphere	Brookhaven Instruments Corp. Current to frequency converter.

9. Daily Beam Calibration

For daily beam calibration all institutions except the U of C, use air filled ionization chambers and one chamber polarization. At some institutions measurements are made of kerma in air. At others blocks made of a variety of materials are used to verify the reproducibility of dose delivers at depth. At one institution both measurements are made.

These practices are listed in Table IX.

TABLE IX

Institution	Kerma/block	Depth in block
MDAH	Lucite block	5 cm
U of C	Kerma in air	_______
FNAL	A-150 block	$10.7 g/cm^2$
GLANTA	Kerma in air & polyethylene block.	5 cm
MANTA	Kerma in air	_______
U of W	Kerma in air	_______

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